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GEOLOGICAL
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MARINE SEISMIC REFRACTION INVESTIGATION OVER THE ORPHEUS GRAVITY ANOMALY OFF THE EAST COAST OF NOVA SCOTIA

G. N. Ewing and George D. Hobson

Price, 75 cents

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Price subject to change without notice

ROGER DUHAMEL, F.R.S.C.
Queen's Printer and Controller of Stationery
Ottawa, Canada
1966

CONTENTS

Illustrations

ABSTRACT

The interpreted results of one single-end and two expanded split-spread refraction profiles are presented. The profiles were obtained off the east coast of Nova Scotia in the vicinity of the Orpheus gravity anomaly. The depth to the crystalline basement is approximately 1.4 km in the area north of the axis of the anomaly. Insufficient shot to receiver distance precluded the possibility of determining the total depth to pre-Carboniferous basement in the area near the axis and to the south of the axis of the anomaly; the minimum depth to basement at these locations is at least two kilometres and probably exceeds three kilometres. An analysis of the time-distance graphs indicates a multi-layered sedimentary rock structure, each layer being defined by characteristic compressional wave velocity.

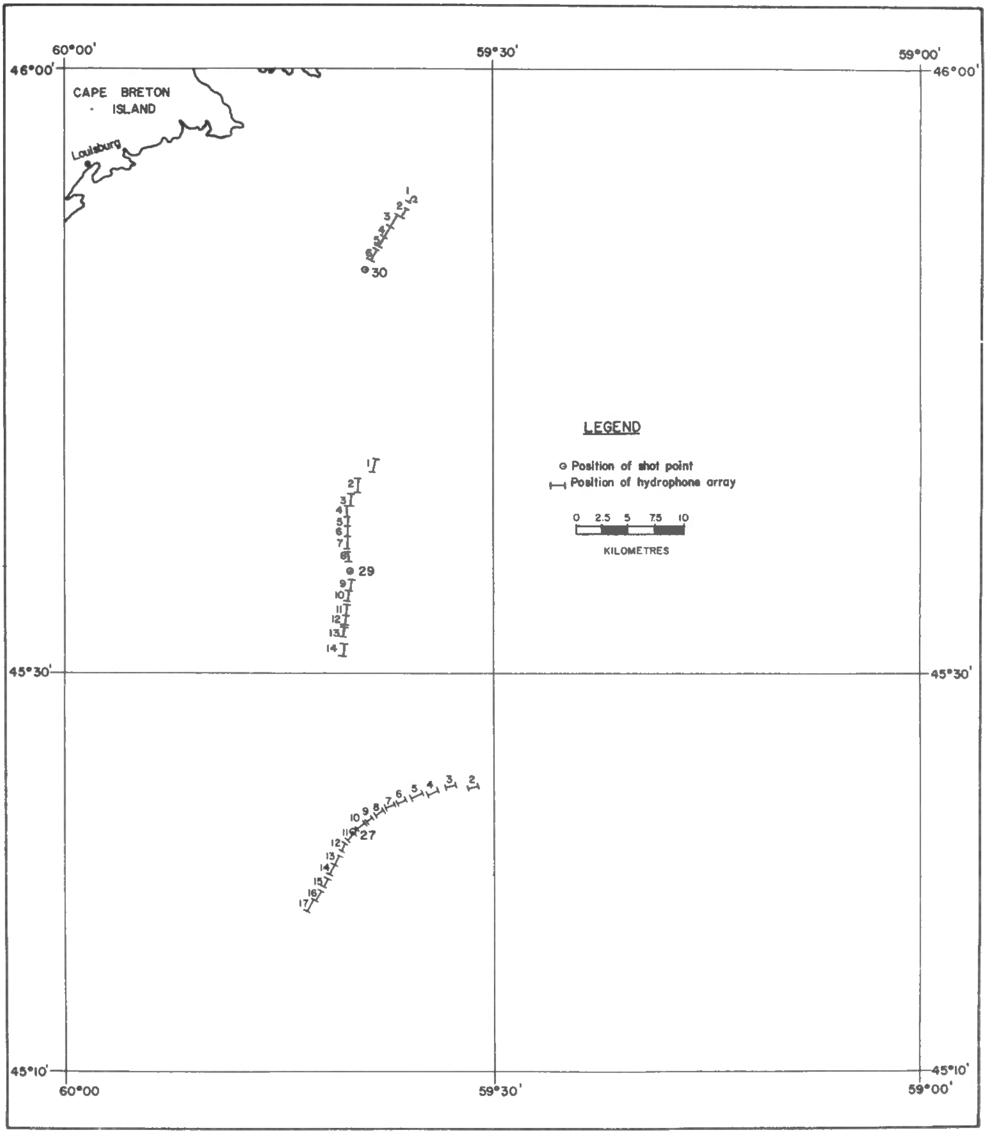

Figure 1. Refraction profiles in the vicinity of the Orpheus gravity anomaly.

MARINE SEISMIC REFRACTION INVESTIGATION OVER THE ORPHEUS GRAVITY ANOMALY OFF THE EAST COAST OF NOVA SCOTIA

INTRODUCTION

In 1964 a belt of negative gravity anomalies was discovered off the east coast of Nova Scotia (Loncarevic, 1965). The anomaly is continuous within the -20 milligal free air gravity anomaly contour for 110 miles, from the entrance of Chedabucto Bay to the southwest wall of the Laurentian channel. This paper presents the results of a study designed to determine the nature of the causitive body or bodies giving rise to the gravity anomaly. G.N. Ewing is with the Bedford Institute of Oceanography, Dartmouth, Nova Scotia and G.D. Hobson is a member of the Geological Survey of Canada. This paper constitutes Bedford Institute Contribution No. 59.

Figure 1 shows the position of the shot points and receiving stations for three seismic refraction profiles over the Orpheus gravity anomaly. Two ships were used (Fig. 2); the shot point was maintained at a fixed location marked by a marker buoy, while the recording ship towed a linear hydrophone array to selected locations along the line of the profile. This procedure does not yield a true reversed refraction profile but does facilitate operations when towing a fixed-array cable as opposed to using single hydrophone stations. The two sections of refraction data, although displaced on opposite sides of the shot location, essentially represent a reversed profile because the same refractors can be distinguished on both profiles. Local changes in the dip of a particular refractor can be determined in the vicinity of the receiver array.

Twelve channels of seismic information were recorded through Texas Instruments model 7000B instruments. A filter setting of L18-K57 was optimum. Seismic energy was detected by Electro Tech EVP-7 pressure sensitive hydrophones, two per trace, attached to a neutrally buoyant cable. Hydrophone stations on the cable are placed at intervals of 76.2 metres with the second take-out for two per trace recording separated by 19.0 metres.

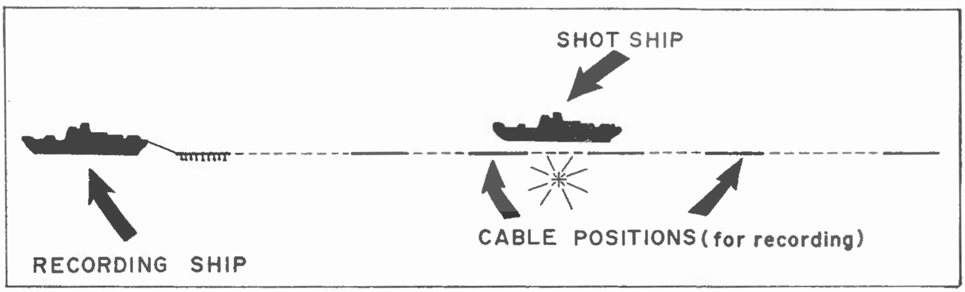

Figure 2. Typical shooting arrangement.

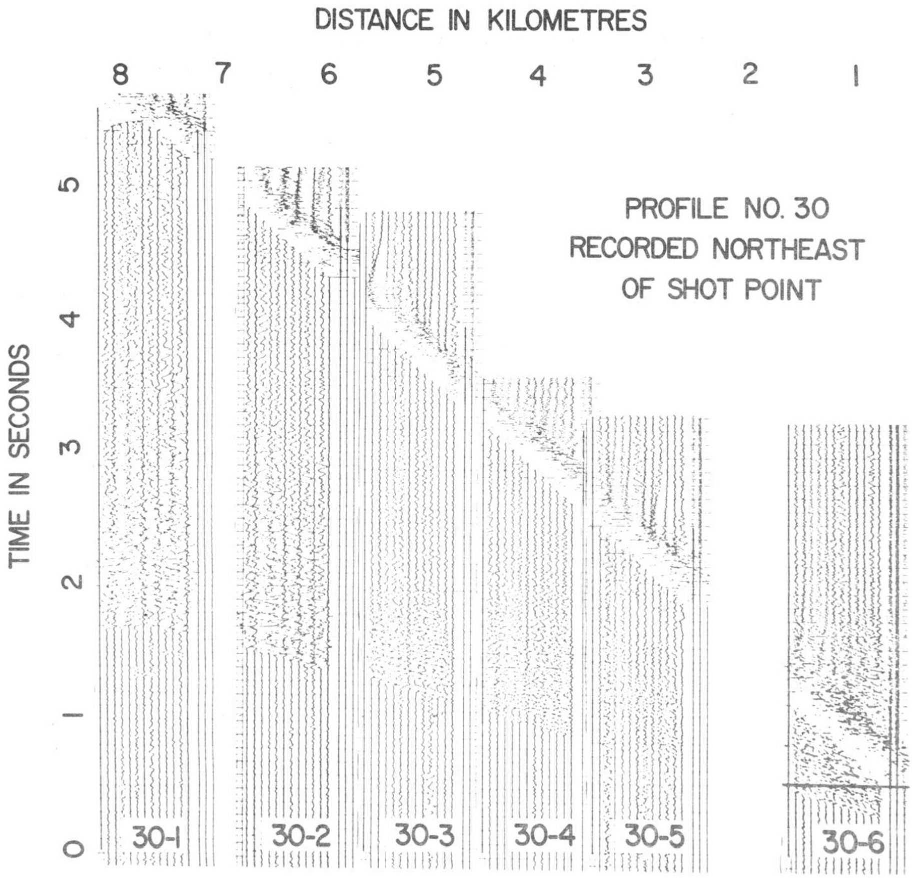

Figure 3. Profile No. 30, northeast of shot point. Note: Clean water wave breaks and absence of second arrivals.

The standard assumptions concerning homogeneity and isotropism for each refractor have been made; conventional methods were used for calculating the depth, dip, thickness, and true velocity of each refractor.

INTERPRETATION

1. Profile No. 30 (Shot Point Location 45°50'N, 59°39'W)

This profile consists of six seismograms recorded in a northeast direction (Fig. 3) from the shot point. The maximum and minimum distance between the shot point and receiver are 7.69 km and 0.77 km respectively. The apparent velocities and calculated thicknesses of the seismic layered structure are shown in Table I.

TABLE I

Velocities and thickness, Profile 30

Layer	Apparent Velocity ($km\ s^{-1}$)	Thickness (km)
1. Water	1.43 (assumed)	0.082 (echo sounder)
2. Sedimentary rock	4.64	0.70
3. Sedimentary rock	5.40	0.64
4. Crystalline basement	6.15	--
Total depth to basement		1.42 km

The depth of water at the shot point, calculated by the seismic refraction method is 0.102 km or about 0.020 km greater than the depth determined by the echo sounder. This discrepancy is overcome by assuming the presence of a thin layer approximately 0.025 km thick of low velocity (2.0 $km\ s^{-1}$) unconsolidated sediment immediately below the water.

2. Profile No. 29 (Shot Point Location 45°35'N, 59°40'W)

This is an expanded split-spread profile, with eight records obtained north of the shot point (Fig. 4) and six records to the south (Fig. 5). The maximum shot-to-receiver distance in the northerly direction is 10.57 km and the minimum is 0.97 km. To the south, the maximum and minimum receiving distances are 8.47 km and 1.02 km respectively. The apparent seismic velocities observed on both sides of the shot point show sufficient similarity to indicate that the same geologic section persists in both directions from that location. The observed apparent velocities, calculated true velocity, and thickness of each layer are given in Table II.

The shot-to-receiver distance on the south spread of the profile was too short to observe an apparent velocity corresponding to the 5.54 km s^{-1} velocity observed on the north spread of the profile. Also, apparent velocities from the pre-Carboniferous basement were not observed on either portion of the profile, because of insufficient shot-to-receiver distance.

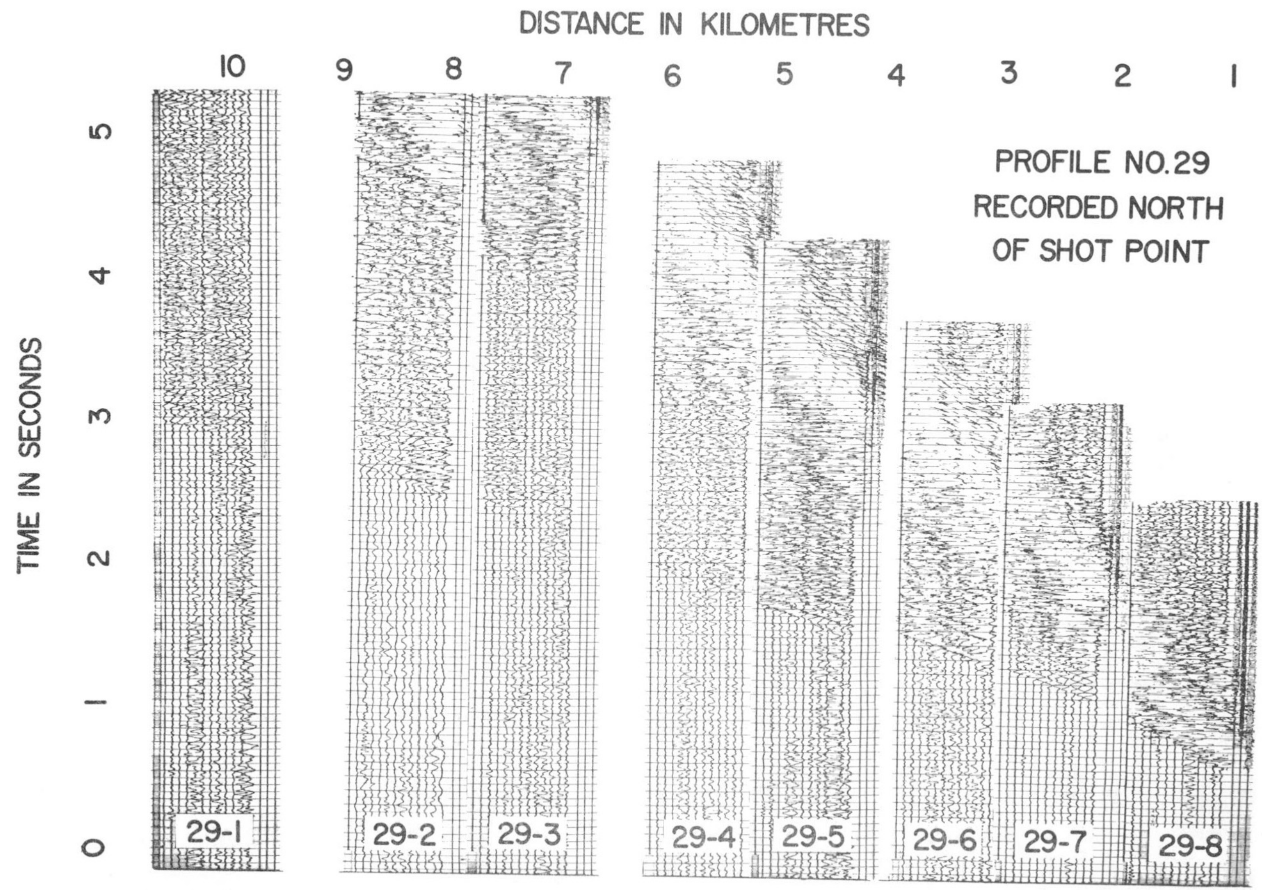

Figure 4. Profile No. 29, north of shot point. Note: Step delay from 29-5 to 29-6.

The apparent velocities on the north spread of the profile are all slightly higher than the corresponding velocities on the south spread indicating that the refractors have a southerly dip (about 2 degrees) along the line of the profile.

The step delay of 0.070 second (Fig. 4) from record 29-5 to 29-6 indicates a rapid change in depth to the top of the 4.36 km s^{-1} refractor (Fig. 8). If the difference in the intercept times of the two linear segments is interpreted as being due to a fault zone then the vertical displacement is of the order of 0.4 km with the shot point on the downthrown side.

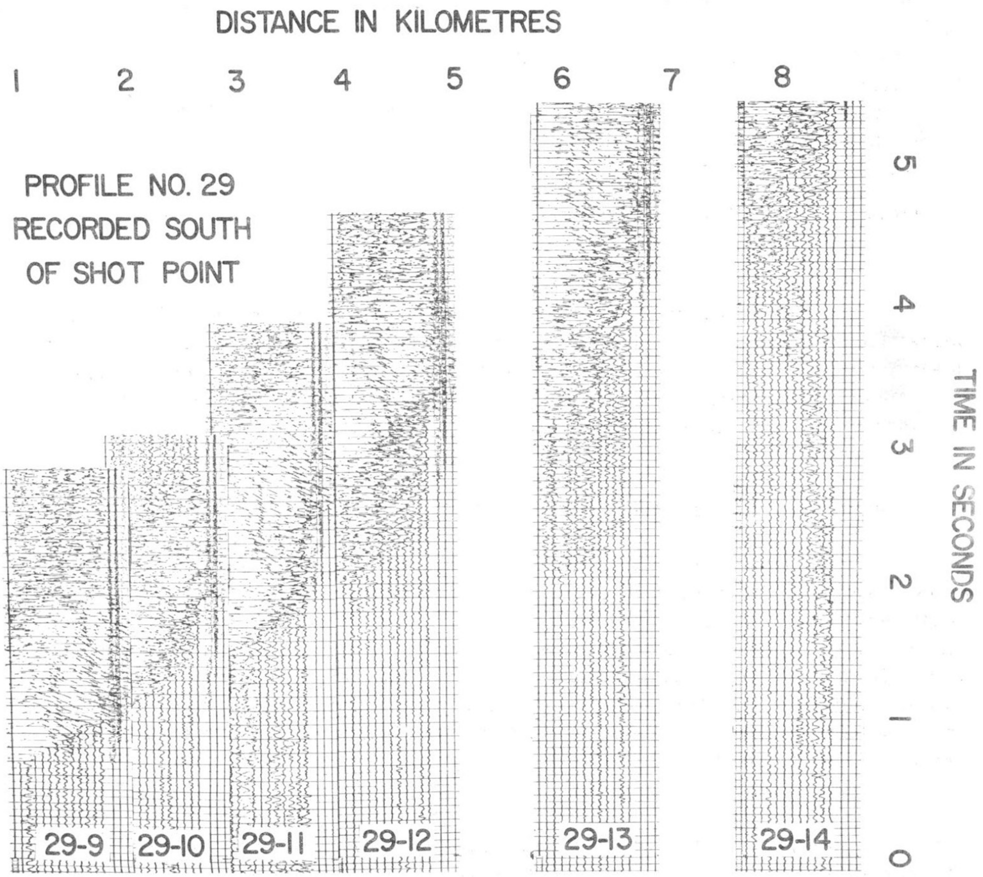

Figure 5. Profile No. 29, south of shot point.
Note: Dominance of second arrivals on 29-11 and 29-12.

TABLE II

Velocities and thickness, Profile 29

Layer	Apparent Velocity (km s^{-1})		True Velocity (km s^{-1})	Thickness (km)
	North	South		
1. Water	--	--	1.43 (assumed)	0.15 (echo-sounder)
2. Unconsolidated sediment	2.32	2.27	2.29	0.28
3. Semiconsolidated sediment	3.88	3.18	3.48	0.41
4. Sedimentary rock	4.43	4.30	4.36	1.14
5. Sedimentary rock	5.54	--	--	--
Depth to crystalline basement			> 3 km	

A third profile was shot in a northwesterly direction from the same shot point as profile No. 29. The northwest profile yielded five poor quality records due to high ambient noise levels that resulted from rough sea conditions existing at the time the profile was shot. These records were not used in the interpretation.

3. Profile No. 27 (Shot Point Location 45°22'N, 59°40'W)

This profile approximates an expanded split-spread. The two ends of the profile were shot in an east-northeast direction (Fig. 6) and a south-southwest (Fig. 7) direction from the shot point. The maximum and minimum shot-to-receiver distances on the northeast profile are 12.20 km and 0.82 km respectively. To the southwest the maximum and minimum shot-to-receiver distances are 8.19 km and 0.25 km respectively. The observed velocities, calculated true velocity, and thickness of each layer are listed in Table III.

The very high apparent velocities observed on the northeast portion of the profile are probably due to local dips on the 5.45 km s^{-1} refractor near the respective receiving locations (27-3 and 27-4). Discussion of the significance of these local dips is not warranted until a more detailed survey is carried out.

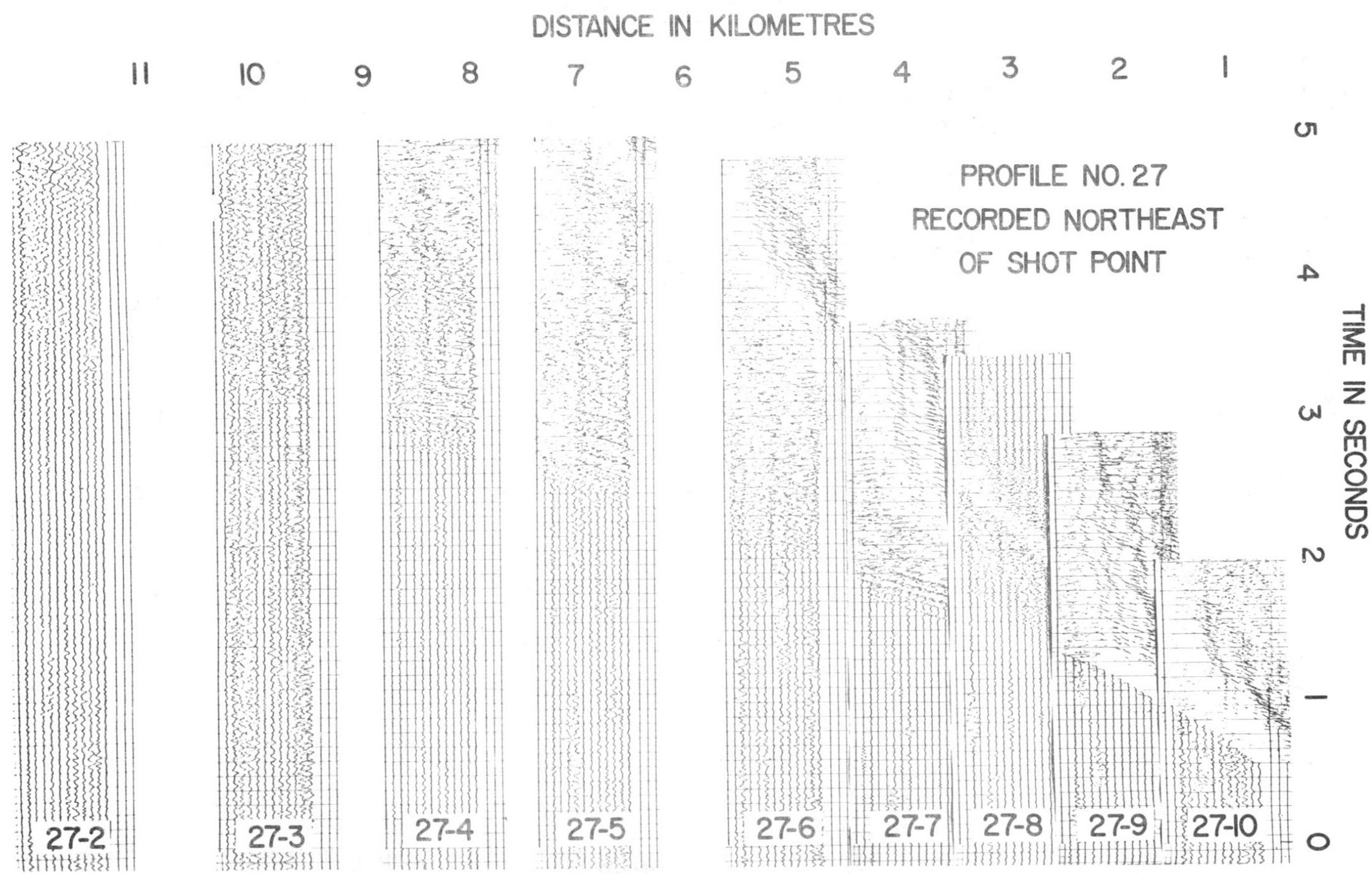

Figure 6. Profile No. 27, northeast of shot point. Note: Step delay from 27-7 to 27-6 and absence of first arrivals on 27-8.

The step delay of 0.068 second noted on Figure 6, from record 27-7 to record 27-6 again indicates a rapid change in the depth to the top of the 4.27 km s^{-1} refractor. A simple calculation of the vertical displacement shows the refractor in the vicinity of the receiving location to be downthrown approximately 0.4 km relative to shot point No. 27, assuming that the 3.48 km s^{-1} refractor is continuous from profile 29 south to profile 27 northeast. If the 3.48 km s^{-1} refractor is not actually continuous to profile 27 then the calculated vertical displacement is approximately 0.2 km.

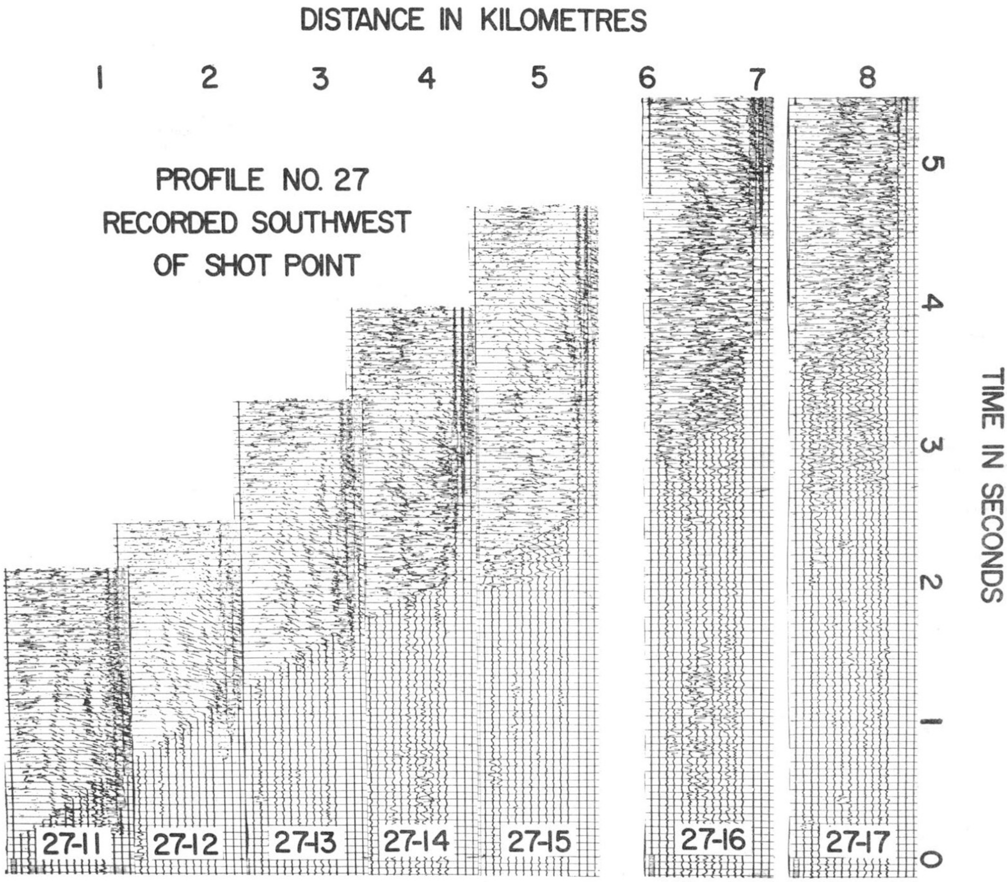

Figure 7. Profile No. 27 southwest of shot point. Note: The well defined second arrivals on 27-15, 27-16, and 27-17.

TABLE III

Velocities and thickness, Profile 27

Layer	Apparent Velocity (km s^{-1}) ENE	Apparent Velocity (km s^{-1}) SSW	True Velocity (km s^{-1})	Thickness (km)
1. Water	--	1.43 (recorded)	1.43	0.093 (echo sounder)
2. Unconsolidated sediment	2.03	2.00) 2.25)	2.02	0.41
3. Sedimentary rock	3.93	4.70	4.27	1.35
4. Sedimentary rock	6.50) 8.50)	5.45	--	--
Depth to crystalline basement			> 2 km	

The second arrivals noted on Figure 5 and Figure 7 show low apparent velocities and have been useful in extrapolating the continuity of the shallow refractors.

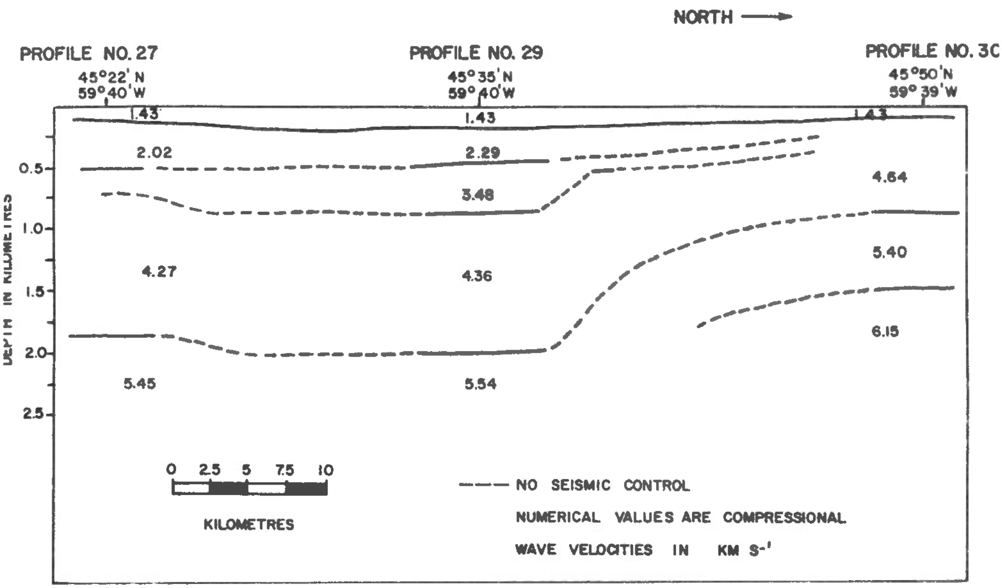

Figure 8. Seismic cross-section over the Orpheus gravity anomaly.

CONCLUSIONS

The characteristic velocities of the seismic layered structure set out in Tables I, II, and III, are very similar to those reported by Drake (1963) in the Gulf of St. Lawrence. In the latter area the sedimentary section is interpreted to be almost entirely Carboniferous in age (Howie and Cumming, 1963).

The seismic cross-section (Fig. 8) has been extrapolated freely from profile to profile across the anomaly. The interpretation quantitatively fits the scant seismic information but fails to delineate a basement configuration that would account for a large negative gravity anomaly. On the basis of the present geophysical evidence it could be that the gravity anomaly is caused by a thick section of low density sedimentary rock that was deposited in a trough-like basement depression. In short, a graben may exist as indicated by the step delays on profile No. 29 north and profile No. 27 northeast. The graben may be infilled with a considerably thicker section of sediments than intimated above.

At present a study is being made in an attempt to show quantitative agreement between the seismic and gravimeter measurements that is consistent with the known local geology. The results of this study will be published later.

ACKNOWLEDGMENTS

The authors wish to thank B.D. Loncarevic for suggesting that a reconnaissance seismic investigation of the Orpheus anomaly be undertaken and for permission to study the free air gravity anomaly map of the area. In addition we thank the Graphic Analyses and Photography sections of the Bedford Institute for preparation of the illustrations.

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